

1. Introduction

This report presents estimates by the United States government of U.S. anthropogenic greenhouse gas emissions and sinks for the years 1990 through 1996.¹ A summary of these estimates is provided in Table 1-2 and Table 1-3 by gas and source category. The emission estimates in these tables are presented on both a full molecular mass basis and on a Global Warming Potential (GWP) weighted basis in order to show the relative contribution of each gas to global average radiative forcing.^{2,3} This report also discusses the methods and data used to calculate these emission estimates.

In June of 1992, the United States signed the United Nations Framework Convention on Climate Change (FCCC). The objective of the FCCC is “to achieve...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.”^{4,5}

Parties to the Convention, by signing, make commitments “to develop, periodically update, publish and make available...national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies...”⁶ The United States views this report as an opportunity to fulfill this commitment under FCCC.

In 1988, preceding the creation of the FCCC, the Intergovernmental Panel on Climate Change (IPCC) was jointly established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). The charter of the IPCC is to assess available scientific information on climate change, assess the environmental and socio-economic impacts of climate change, and formulate response strategies (IPCC 1996). Under Working Group 1 of the IPCC, nearly 140 scientists and national experts from more than thirty countries corroborated in the creation of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) to ensure that the emission inventories submitted to the FCCC are consistent and comparable across sectors and between nations. The *Revised 1996 IPCC Guidelines* were accepted by the IPCC at its Twelfth Session (Mexico City, 11-13 September 1996). The information provided in this inventory is presented in accordance with these guidelines, unless otherwise noted. Additionally, in order to fully comply with the *Revised 1996 IPCC Guidelines*, the United States has provided a copy of the IPCC reporting tables in Annex N and in Annex O estimates of carbon dioxide emissions from fossil fuel combustion using the IPCC Reference Approach.

¹ Preliminary U.S. greenhouse gas emission estimates for the year 1997 are also provided in Annex P.

² See the section below entitled *Global Warming Potential Concept* for an explanation of GWP values.

³ See the section below entitled *What is Climate Change?* for an explanation of radiative forcing.

⁴ The term “anthropogenic”, in this context, refers to greenhouse gas emissions and removals that are a direct result of human activities or are the result of natural processes that have been affected by human activities (IPCC/UNEP/OECD/IEA 1997).

⁵ Article 2 of the Framework Convention on Climate Change published by the UNEP/WMO Information Unit on Climate Change.

⁶ Article 4 of the Framework Convention on Climate Change published by the UNEP/WMO Information Unit on Climate Change (also identified in Article 12).

Overall, the purpose of an inventory of anthropogenic greenhouse gas emissions is (1) to provide a basis for the ongoing development of methodologies for estimating sources and sinks of greenhouse gases; (2) to provide a common and consistent mechanism through which Parties to the FCCC can estimate emissions and compare the relative contribution of individual sources, gases, and nations to climate change; and (3) as a prerequisite for evaluating the cost-effectiveness and feasibility of pursuing possible mitigation strategies.

What is Climate Change?

The Earth naturally absorbs and reflects incoming solar radiation and emits longer wavelength terrestrial (thermal) radiation back into space. On average, the absorbed solar radiation is balanced by the outgoing terrestrial radiation emitted to space. A portion of this terrestrial radiation, though, is itself absorbed by gases in the atmosphere. The energy from this absorbed terrestrial radiation warms the Earth's surface and atmosphere, creating what is known as the "natural greenhouse effect." Without the natural heat-trapping properties of these atmospheric gases, the average surface temperature of the Earth would be about 34°C lower (IPCC 1996).

Although the Earth's atmosphere consists mainly of oxygen and nitrogen, neither play a significant role in this greenhouse effect because both are essentially transparent to terrestrial radiation. The greenhouse effect is primarily a function of the concentration of water vapor, carbon dioxide, and other trace gases in the atmosphere that absorb the terrestrial radiation leaving the surface of the Earth (IPCC 1996). Changes in the atmospheric concentrations of these greenhouse gases can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth-atmosphere system (IPCC 1996). Holding everything else constant, increases in greenhouse gas concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth).

Under the United Nations FCCC, the definition of climate change is "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."⁷ Given that definition, in its 1995 assessment of the science of climate change, the IPCC concluded that:

Human activities are changing the atmospheric concentrations and distributions of greenhouse gases and aerosols. These changes can produce a radiative forcing by changing either the reflection or absorption of solar radiation, or the emission and absorption of terrestrial radiation (IPCC 1996).

The IPCC went on to report in its assessment that the "[g]lobal mean surface temperature [of the Earth] has increased by between about 0.3 and 0.6 °C since the late 19th century..." (IPCC 1996) and finally concluded with the following statement:

Our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors. These include the magnitude and patterns of long term natural variability and the time-evolving pattern of forcing by, and response to, changes in concentrations of greenhouse gases and aerosols, and land surface changes. Nevertheless, the balance of the evidence suggests that there is a discernable human influence on global climate (IPCC 1996).

Greenhouse Gases

Climate change can be driven by changes in the atmospheric concentrations of a number of radiatively active gases and aerosols. We have clear evidence that human activities have affected concentrations, distributions and life cycles of these gases (IPCC 1996).

Naturally occurring greenhouse gases include water vapor, carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and ozone (O₃). Several classes of haloge-

⁷ Article 1 of the Framework Convention on Climate Change published by the UNEP/WMO Information Unit on Climate Change.

nated substances that contain fluorine, chlorine, or bromine are also greenhouse gases, but they are, for the most part, emitted solely by human activities. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are halocarbons that contain chlorine, while halocarbons that contain bromine are referred to as halons. Other fluorine containing halogenated substances include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). There are also several gases that, although they do not have a direct radiative forcing effect, do influence the formation and destruction of ozone, which does have such a terrestrial radiation absorbing effect. These gases—referred to here as ozone precursors—include carbon monoxide (CO), oxides of nitrogen (NO_x), and nonmethane volatile organic compounds (NMVOCs).⁸ Aerosols—extremely small particles or liquid droplets often produced by emissions of sulfur dioxide (SO_2)—can also affect the absorptive characteristics of the atmosphere.

Carbon dioxide, methane, and nitrous oxide are continuously emitted to and removed from the atmosphere by natural processes on Earth. Anthropogenic activities, however, can cause additional quantities of these and other greenhouse gases to be emitted or sequestered, thereby changing their global average atmospheric concentrations. Natural activities such as respiration by plants or animals and seasonal cycles of plant growth and decay are examples of processes that only cycle carbon or nitrogen between the atmosphere and organic biomass. Such processes—except when directly or indirectly perturbed out of equilibrium by anthropogenic activities—generally do not alter average atmospheric greenhouse gas concentrations over decadal timeframes. Climatic changes resulting from anthropogenic activities, however, could have positive or negative feedback effects on these natural systems.

A brief description of each greenhouse gas, its sources, and its role in the atmosphere is given below. The following section then explains the concept of Global Warming Potentials (GWPs), which are assigned to

individual gases as a measure of their relative average global radiative forcing effect.

Water Vapor (H_2O). Overall, the most abundant and dominant greenhouse gas in the atmosphere is water vapor. Water vapor is neither long-lived nor well-mixed in the atmosphere, varying spatially from 0 to 2 percent (IPCC 1996). In addition, atmospheric water can exist in several physical states including gaseous, liquid, and solid. Human activities are not believed to directly affect the average global concentration of water vapor; however, the radiative forcing produced by the increased concentrations of other greenhouse gases may indirectly affect the hydrologic cycle. A warmer atmosphere has an increased water holding capacity; yet, increased concentrations of water vapor affects the formation of clouds, which can both absorb and reflect solar and terrestrial radiation.

Carbon Dioxide (CO_2). In nature, carbon is cycled between various atmospheric, oceanic, land biotic, marine biotic, and mineral reservoirs. The largest fluxes occur between the atmosphere and terrestrial biota, and between the atmosphere and surface water of the oceans. In the atmosphere, carbon predominantly exists in its oxidized form as CO_2 . Atmospheric carbon dioxide is part of this global carbon cycle, and therefore its fate is a complex function of geochemical and biological processes. Carbon dioxide concentrations in the atmosphere, as of 1994, increased from approximately 280 parts per million by volume (ppmv) in pre-industrial⁹ times to 358 ppmv, a more than 25 percent increase (IPCC 1996).¹⁰ The IPCC has stated that “[t]here is no doubt that this increase is largely due to human activities, in particular fossil fuel combustion...” (IPCC 1996). Forest clearing, other biomass burning, and some non-energy production processes (e.g., cement production) also emit notable quantities of carbon dioxide.

In its latest scientific assessment, the IPCC also stated that “[t]he increased amount of carbon dioxide [in the atmosphere] is leading to climate change and will produce, on average, a global warming of the Earth’s

⁸ Also referred to in the U.S. Clean Air Act as “criteria pollutants.”

⁹ The pre-industrial period is defined as the time preceding the year 1750 (IPCC 1996).

¹⁰ Carbon dioxide concentrations during the last 1,000 years of the pre-industrial period (1650-1750), a time of relative climate stability, fluctuated by about ± 10 ppmv around 280 ppmv (IPCC 1996).

surface because of its enhanced greenhouse effect—although the magnitude and significance of the effects are not fully resolved” (IPCC 1996).

Methane (CH_4). Methane is produced through anaerobic decomposition of organic matter in biological systems. Agricultural processes such as wetland rice cultivation, enteric fermentation in animals, and the decomposition of animal wastes emit CH_4 , as does the decomposition of municipal solid wastes. Methane is also emitted during the production and distribution of natural gas and petroleum, and is released as a by-product of coal mining and incomplete fossil fuel combustion. The average global concentration of methane in the atmosphere was 1,720 parts per billion by volume (ppbv) in 1994, a 145 percent increase from the pre-industrial concentration of 700 ppbv (IPCC 1996). It is estimated that 60 to 80 percent of current CH_4 emissions are the result of anthropogenic activities. Carbon isotope measurements indicate that roughly 20 percent of methane emissions are from fossil fuel consumption, and an equal percentage is produced by natural wetlands, which will likely increase with rising temperatures and rising microbial action (IPCC 1996).

Methane is removed from the atmosphere by reacting with the hydroxyl radical (OH) and is ultimately converted to CO_2 . Increasing emissions of methane, though, reduces the concentration of OH, and thereby the rate of further methane removal (IPCC 1996).

Nitrous Oxide (N_2O). Anthropogenic sources of N_2O emissions include agricultural soils, especially the use of synthetic and manure fertilizers; fossil fuel combustion, especially from mobile sources; adipic (nylon) and nitric acid production; wastewater treatment and waste combustion; and biomass burning. The atmospheric concentration of nitrous oxide (N_2O) in 1994 was about 312 parts per billion by volume (ppbv), while pre-industrial concentrations were roughly 275 ppbv. The majority of this 13 percent increase has occurred after

the pre-industrial period and is most likely due to anthropogenic activities (IPCC 1996). Nitrous oxide is removed from the atmosphere primarily by the photolytic action of sunlight in the stratosphere.

Ozone (O_3). Ozone is present in both the stratosphere,¹¹ where it shields the Earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere¹², where it is the main component of anthropogenic photochemical “smog”. During the last two decades, emissions of anthropogenic chlorine and bromine-containing halocarbons, such as chlorofluorocarbons (CFCs), have depleted stratospheric ozone concentrations. This loss of ozone in the stratosphere has resulted in negative radiative forcing, representing an indirect effect of anthropogenic emissions of chlorine and bromine compounds (IPCC 1996).

Tropospheric ozone, which is also a greenhouse gas, is produced from the oxidation of methane and from reactions with precursor gases such as carbon monoxide (CO), nitrogen oxides (NO_x), and non-methane volatile organic compounds (NMVOCs). This latter group of ozone precursors are included in the category referred to as “criteria pollutants” in the United States under the Clean Air Act¹³ and its subsequent amendments. The tropospheric concentrations of both ozone and these precursor gases are short-lived and, therefore, spatially variable.

Halocarbons. Halocarbons are for the most part man-made chemicals that have both direct and indirect radiative forcing effects. Halocarbons that contain chlorine—chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), methyl chloroform, and carbon tetrachloride—and bromine—halons and methyl bromide—result in stratospheric ozone depletion and are therefore controlled under the *Montreal Protocol on Substances that Deplete the Ozone Layer*. Although CFCs and HCFCs include potent global warming gases, their net radiative forcing effect on the atmosphere is reduced be-

¹¹ The stratosphere is the layer from the troposphere up to roughly 50 kilometers. In the lower regions the temperature is nearly constant but in the upper layer the temperature increases rapidly because of sunlight absorption by the ozone-layer. The ozone-layer is the part of the stratosphere from 19 kilometers up to 48 kilometers where the concentration of ozone reaches up to 10 parts per million.

¹² The troposphere is the layer from the ground up to 11 kilometers near the poles and up to 16 kilometers in equatorial regions (i.e., the lowest layer of the atmosphere where people live). It contains roughly 80 percent of the mass of all gases in the atmosphere and is the site for most weather processes, including most of the water vapor and clouds.

¹³ [42 U.S.C § 7408, CAA § 108]

cause they cause stratospheric ozone depletion, which is itself an important greenhouse gas in addition to shielding the Earth from harmful levels of ultraviolet radiation. Under the *Montreal Protocol*, the United States phased-out the production and importation of halons by 1994 and of CFCs by 1996. Under the Copenhagen Amendments to the *Protocol*, a cap was placed on the production and importation of HCFCs by non-Article 5¹⁴ countries beginning in 1996, and then followed by a complete phase-out by the year 2030. The ozone depleting gases covered under the *Montreal Protocol* and its Amendments are not covered by the FCCC; however, they are reported in this inventory under Annex K.

Perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), and sulfur hexafluoride (SF₆) are not ozone depleting substances, and therefore are not covered under the *Montreal Protocol*. They are, however, powerful greenhouse gases. HFCs—primarily used as replacements for ozone depleting substances but also emitted as a by-product of the HCFC-22 manufacturing process—currently have a small aggregate radiative forcing impact; however, it is anticipated that their contribution to overall radiative forcing will increase (IPCC 1996). PFCs and SF₆ are predominantly emitted from various industrial processes including aluminum smelting, semiconductor manufacturing, electric power transmission and distribution, and magnesium casting. Currently, the radiative forcing impact of PFCs, and SF₆ is also small; however, because they have extremely long atmospheric lifetimes, their concentrations tend to irreversibly accumulate in the atmosphere.

Carbon Monoxide (CO). Carbon monoxide has an indirect radiative forcing effect by elevating concentrations of CH₄ and tropospheric ozone through chemical reactions with other atmospheric constituents (e.g., the hydroxyl radical) that would otherwise assist in destroying CH₄ and tropospheric ozone. Carbon monoxide is created when carbon-containing fuels are burned incompletely. Through natural processes in the atmo-

sphere, it is eventually oxidized to CO₂. Carbon monoxide concentrations are both short-lived in the atmosphere and spatially variable.

Nitrogen Oxides (NO_x). The primary climate change effects of nitrogen oxides (i.e., NO and NO₂) are indirect and result from their role in promoting the formation of tropospheric, and to a lesser degree, lower stratospheric, ozone. (NO_x emissions injected higher in the stratosphere¹⁵ can lead to stratospheric ozone depletion.). Nitrogen oxides are created from lightning, soil microbial activity, biomass burning (both natural and anthropogenic fires), fossil fuel combustion, and, in the stratosphere, from nitrous oxide (N₂O). Concentrations of NO_x are both relatively short-lived in the atmosphere and spatially variable.

Nonmethane Volatile Organic Compounds (NMVOCs). Nonmethane volatile organic compounds include compounds such as propane, butane, and ethane. These compounds participate, along with NO_x, in the formation of tropospheric ozone and other photochemical oxidants. NMVOCs are emitted primarily from transportation and industrial processes, as well as biomass burning and non-industrial consumption of organic solvents. Concentrations of NMVOCs tend to be both short-lived in the atmosphere and spatially variable.

Aerosols. Aerosols are extremely small particles or liquid droplets found in the atmosphere. They can be produced by natural events such as dust storms and volcanic activity or by anthropogenic processes such as fuel combustion. Their effect upon radiative forcing is to both absorb radiation and to alter cloud formation, thereby affecting the reflectivity (i.e., albedo) of the Earth. Aerosols are removed from the atmosphere primarily by precipitation, and generally have short atmospheric lifetimes. Like ozone precursors, aerosol concentrations and composition vary by region (IPCC 1996).

Anthropogenic aerosols in the troposphere are primarily the result of sulfur dioxide (SO₂)¹⁶ emissions from fossil fuel and biomass burning. Overall, aerosols tend

¹⁴ Article 5 of the *Montreal Protocol* covers several groups of countries, especially developing countries, with low consumption rates of ozone depleting substances. Developing countries with per capita consumption of less than 0.3 kg receive financial assistance and a grace period of ten additional years in the phase-out of ozone depleting substances.

¹⁵ Primarily from fuel combustion emissions from high altitude aircraft.

¹⁶ Sulfur dioxide is a primary anthropogenic contributor to the formation of “acid rain” and other forms of atmospheric acid deposition.

to produce a negative radiative forcing effect (i.e., net cooling effect on the climate), although because they are short-lived in the atmosphere—lasting days to weeks—their concentrations respond rapidly to changes in emissions.¹⁷ Locally, the negative radiative forcing effects of aerosols can offset the positive forcing of greenhouse gases (IPCC 1996). “However, the aerosol effects do not cancel the global-scale effects of the much longer-lived greenhouse gases, and significant climate changes can still result” (IPCC 1996). Emissions of sulfur dioxide are provided in Annex L of this report.

Global Warming Potentials

The Global Warming Potential (GWP) is intended as a quantified measure of the relative radiative forcing impacts of various greenhouse gases. It is defined as the cumulative radiative forcing—both direct and indirect effects—over a specified time horizon resulting from the emission of a unit mass of gas relative to some reference gas (IPCC 1996). Direct effects occur when the gas itself is a greenhouse gas. Indirect radiative forcing occurs when chemical transformations involving the original gas produces a gas or gases that are greenhouse gases, or when a gas influences the atmospheric lifetimes of other gases. The reference gas used is CO₂, in which case GWP weighted emissions are measured in million metric tons of carbon equivalents (MMTCE). Carbon comprises 12/44ths of carbon dioxide by weight. In order to convert emissions reported in teragrams (Tg) of a gas to MMTCE, the following equation is used:

$$\text{MMTCE} = (\text{Tg of gas}) \times (\text{GWP}) \times \left(\frac{12}{44} \right)$$

where,

MMTCE = Million Metric Tons of Carbon Equivalents

Tg = Teragrams (equivalent to million metric tons)

GWP = Global Warming Potential

$$\left(\frac{12}{44} \right) = \text{Carbon to CO}_2 \text{ molecular weight ratio.}$$

GWP values allow policy makers to compare the impacts of emissions and reductions of different gases. According to the IPCC, GWPs typically have an uncertainty of ±35 percent. The parties to the FCCC have also agreed to use GWPs based upon a 100 year time horizon although other time horizon values are available (see Table 1-1).

*In addition to communicating emissions in units of mass, Parties may choose also to use global warming potentials (GWPs) to reflect their inventories and projections in carbon dioxide-equivalent terms, using information provided by the Intergovernmental Panel on Climate Change (IPCC) in its Second Assessment Report. Any use of GWPs should be based on the effects of the greenhouse gases over a 100-year time horizon. In addition, Parties may also use other time horizons.*¹⁸

Table 1-1: Global Warming Potentials and Atmospheric Lifetimes (Years)

Gas	Atmospheric Lifetime	GWP ^a
Carbon dioxide (CO ₂)	50-200	1
Methane (CH ₄) ^b	12 ± 3	21
Nitrous oxide (N ₂ O)	120	310
HFC-23	264	11,700
HFC-125	32.6	2,800
HFC-134a	14.6	1,300
HFC-143a	48.3	3,800
HFC-152a	1.5	140
HFC-227ea	36.5	2,900
HFC-236fa	209	6,300
HFC-4310mee	17.1	1,300
CF ₄	50,000	6,500
C ₂ F ₆	10,000	9,200
C ₂ F ₁₀	2,600	7,000
C ₆ F ₁₄	3,200	7,400
SF ₆	3,200	23,900

Source: (IPCC 1996)

^a 100 year time horizon

^b The methane GWP includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO₂ is not included.

¹⁷ Volcanic activity can inject significant quantities of aerosol producing sulfur dioxide and other sulfur compounds into the stratosphere, which can result in a longer negative forcing effect (i.e., a few years) (IPCC 1996).

¹⁸ Framework Convention on Climate Change; FCCC/CP/1996/15/Add.1; 29 October 1996; Report of the Conference of the Parties on Its Second Session; Held at Geneva from 8 To 19 July 1996; Addendum; Part Two: Action Taken By The Conference Of The Parties At Its Second Session; Decision 9/CP.2; Communications from Parties included in Annex I to the Convention: guidelines, schedule and process for consideration; Annex: Revised Guidelines for the Preparation of National Communications by Parties Included in Annex I to the Convention; p. 18.

Greenhouse gases with long atmospheric lifetimes (e.g., CO₂, CH₄, N₂O, HFCs, PFCs, and SF₆) tend to be evenly distributed throughout the atmosphere, and consequently global average concentrations can be determined. The short-lived gases such as water vapor, tropospheric ozone, ozone precursors (e.g., NO_x, CO, and NMVOCs), and tropospheric aerosols (e.g., SO₂ products), however, vary regionally, and consequently it is difficult to quantify their global radiative forcing impacts. No GWP values are attributed to gases that are short-lived and spatially inhomogeneous in the atmosphere. Other greenhouse gases not yet listed by the Intergovernmental Panel on Climate Change (IPCC), but are already or soon will be in commercial use include: HFC-245fa, hydrofluoroethers (HFEs), and nitrogen trifluoride (NF₃).

Organization of Report

In accordance with the IPCC guidelines for reporting contained in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997), this U.S. inventory of greenhouse gas emissions is segregated into six sector-specific chapters, listed below:

Within each chapter, emissions are identified by the anthropogenic activity that is the source of the greenhouse gas emissions being estimated (e.g., coal mining). Overall, the following organizational structure is consistently applied throughout this report:

Chapter/Sector: Overview of emission trends for sector

Source: Description of source pathway and emission trends from 1990 through 1996

- **Methodology:** Description of analytical methods employed to produce emission estimates
- **Data Sources:** Identification of primary data references, primarily for activity data and emission factors
- **Uncertainty:** Discussion of relevant issues related to the uncertainty in the emission estimates presented

Special attention is given to carbon dioxide from fossil fuel combustion relative to other sources because of its share of emissions relative to other sources. For it, each energy consuming end-use is treated individually. Additional information is also provided in the Annexes (see box on following page).

Recent Trends in U.S. Greenhouse Gas Emissions

Total U.S. greenhouse gas (GHG) emissions rose in 1996 to 1,788.0 MMTCE (9.5 percent above 1990 baseline levels). The largest single year increase in emissions over this time period was registered in 1996 (57.0 MMTCE or 3.3 percent) (see Figure 1-1).

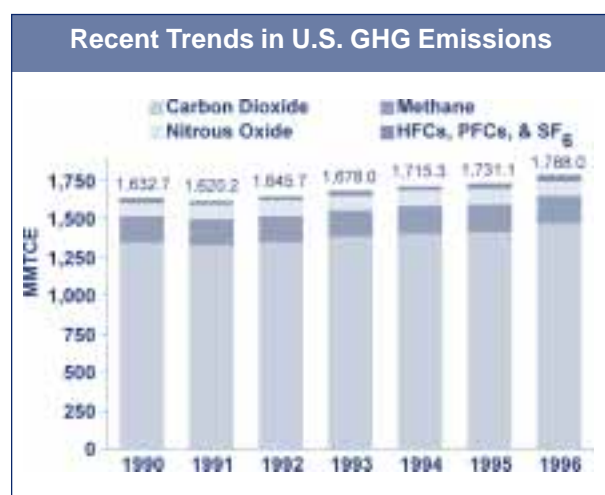
Sectors	Activities Included
Energy	Emissions of all greenhouse gases resulting from stationary and mobile energy activities including fuel combustion and fugitive fuel emissions.
Industrial Processes	By-product or fugitive emissions of greenhouse gases from industrial processes not directly related to energy activities such as fossil fuel combustion.
Solvent Use	Emissions, of primarily non-methane volatile organic compounds (NMVOCs), resulting from the use of solvents.
Agriculture	Anthropogenic emissions from agricultural activities except fuel combustion and sewage emissions, which are addressed under the Energy and Waste sectors, respectively.
Land-Use Change and Forestry	Emissions and removals from forest and land-use change activities, primarily carbon dioxide.
Waste	Emissions from waste management activities.

Source: (IPCC/UNEP/OECD/IEA 1997)

ANNEX A	Methodology for Estimating Emissions of CO ₂ from Fossil Fuel Combustion
ANNEX B	Methodology for Estimating Emissions of CH ₄ , N ₂ O, and Criteria Pollutants from Stationary Combustion
ANNEX C	Methodology for Estimating Emissions of CH ₄ , N ₂ O, and Criteria Pollutants from Mobile Combustion
ANNEX D	Methodology for Estimating Methane Emissions from Coal Production
ANNEX E	Methodology for Estimating Methane Emissions from Natural Gas Systems
ANNEX F	Methodology for Estimating Methane Emissions from Petroleum Systems
ANNEX G	Methodology for Estimating Methane Emissions from Enteric Fermentation
ANNEX H	Methodology for Estimating Methane Emissions from Manure Management
ANNEX I	Methodology for Estimating Methane Emissions from Landfills
ANNEX J	Global Warming Potentials
ANNEX K	Ozone Depleting Substance Emissions
ANNEX L	Sulfur Dioxide Emissions
ANNEX M	Complete List of Sources
ANNEX N	IPCC Reporting Tables
ANNEX O	IPCC Reference Approach for Estimating CO ₂ Emissions from Fossil Fuel Combustion
ANNEX P	Preliminary 1997 Estimates of U.S. Greenhouse Gas Emissions and Sinks
ANNEX Q	Sources of Greenhouse Gas Emissions Excluded

The largest source of U.S. GHG emissions was carbon dioxide (CO₂) from fossil fuel combustion, which accounted for 81 percent of weighted emissions in 1996. Emissions from this source grew by 9 percent (118.9 MMTCE) over the seven year period and were responsible for over two-thirds of the increase in national emissions. The largest annual increase in emissions was registered in 1996, when increased fossil fuel consumption drove up energy related CO₂ emissions by 3.7 percent.

Figure 1-1

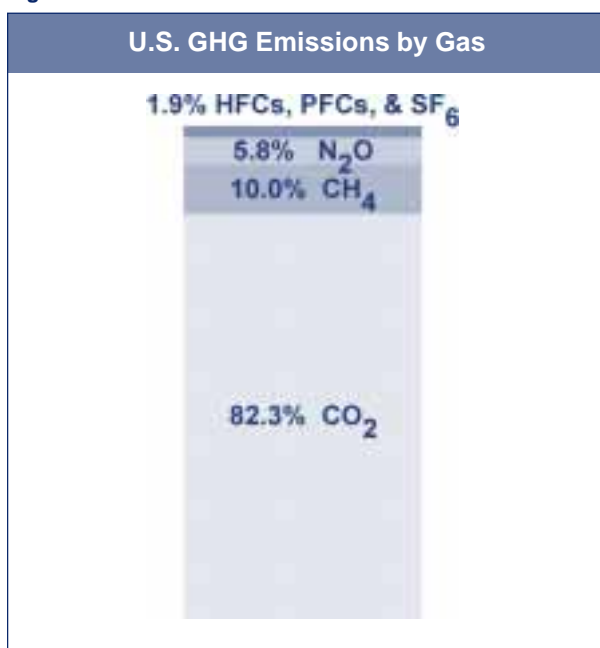


The primary factors for this later single year increase were (1) fuel switching by electric utilities from natural gas to more carbon intensive coal as gas prices rose sharply, (2) higher petroleum consumption in the transportation end-use sector as travel increased and fuel efficiency stagnated, (3) greater natural gas consumption for heating in the residential end-use sector due to colder weather, and (4) overall robust domestic economic growth.

Other significant trends in emissions over the seven year period of 1990 through 1996 included:

- Combined nitrous oxide (N₂O) and methane (CH₄) emissions from mobile source fossil fuel combustion rose 3.2 MMTCE (22 percent), primarily due to increased rates of N₂O generation in highway vehicles.
- Aggregate hydrofluorocarbon (HFC) and perfluorocarbon (PFC) emissions resulting from the substitution of ozone depleting substances (e.g., CFCs) increased dramatically (by 11.6 MMTCE); however PFC emissions from aluminum production decreased significantly (41 percent) as a result of both voluntary industry emission reduction efforts and falling domestic aluminum production.

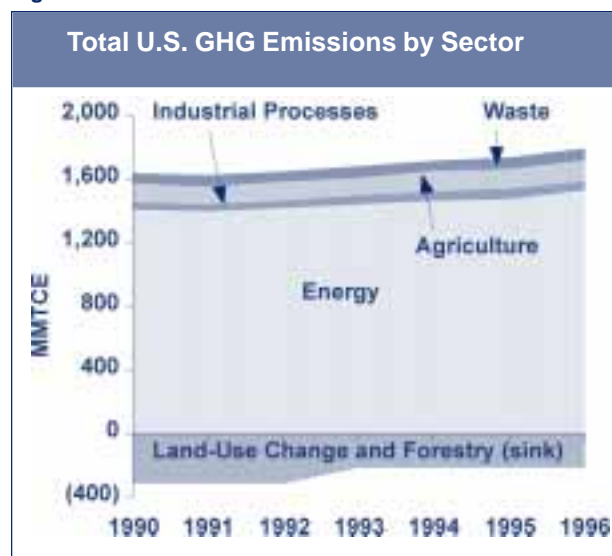
Figure 1-2



- Methane emissions from the decomposition of waste in municipal and industrial landfills rose by 8.9 MMTCE (16 percent) as the amount of organic matter in landfills steadily accumulated.
- Emissions from coal mining dropped by 5.1 MMTCE (21 percent) as the use of methane from degasification systems increased significantly.
- Nitrous oxide emissions from agricultural soil management increased by 6.2 MMTCE (10 percent) as fertilizer consumption and cultivation of nitrogen fixing crops rose.

Overall, from 1990 to 1996 total emissions of CO₂, CH₄, and N₂O increased by 122.8 (9 percent), 8.6 (5 percent), and 11.4 MMTCE (12 percent), respectively. During the same period, weighted emissions of HFCs, PFCs, and SF₆ rose by 12.5 MMTCE (56 percent). Despite being emitted in smaller quantities, emissions of HFCs, PFCs, and SF₆ are significant because of their extremely

Figure 1-3



high global warming potentials and, in the cases of PFCs and SF₆, long atmospheric lifetimes. U.S. greenhouse gas emissions were partly offset by carbon sequestration in forests.

Alternatively, over the seven year period emissions from the Energy, Industrial Processes, Agriculture, and Waste sectors climbed by 120.2 (9 percent), 16.1 (35 percent), 9.9 (9 percent), and 9.1 MMTCE (15 percent), respectively. Estimates of the quantity of carbon sequestered under the Land-Use Change and Forestry sector, although based on projections, declined in absolute value by 103.0 MMTCE (33 percent).

Table 1-2 summarizes emissions and sinks from all U.S. anthropogenic sources weighted units of MMTCE, while unweighted gas emissions and sinks in teragrams (Tg) are provided in Table 1-3. Alternatively, emissions and sinks are aggregated by sector in Table 1-4 and Figure 1-3.

Table 1-2: U.S. Greenhouse Gas Emissions and Sinks (MMTCE)

Gas/Source	1990	1991	1992	1993	1994	1995	1996
CO₂	1,348.3	1,333.2	1,353.4	1,385.6	1,408.5	1,419.2	1,471.1
Fossil Fuel Combustion	1,331.4	1,316.4	1,336.6	1,367.5	1,389.6	1,398.7	1,450.3
Natural Gas Flaring	2.0	2.2	2.2	3.0	3.0	3.7	3.5
Cement Manufacture	8.9	8.7	8.8	9.3	9.6	9.9	10.1
Lime Manufacture	3.3	3.2	3.3	3.4	3.5	3.7	3.8
Limestone and Dolomite Use	1.4	1.3	1.2	1.1	1.5	1.8	1.8
Soda Ash Manufacture and Consumption	1.1	1.1	1.1	1.1	1.1	1.2	1.2
Carbon Dioxide Manufacture	0.2	0.2	0.2	0.2	0.2	0.3	0.3
Land-Use Change and Forestry (Sink)*	(311.5)	(311.5)	(311.5)	(208.6)	(208.6)	(208.6)	(208.6)
CH₄	169.9	171.1	172.5	171.9	175.9	179.2	178.6
Stationary Sources	2.3	2.3	2.4	2.3	2.3	2.4	2.5
Mobile Sources	1.5	1.4	1.4	1.4	1.4	1.4	1.4
Coal Mining	24.0	22.8	22.0	19.2	19.4	20.3	18.9
Natural Gas Systems	32.9	33.3	33.9	34.1	33.9	33.8	34.1
Petroleum Systems	1.6	1.6	1.6	1.6	1.6	1.6	1.5
Petrochemical Production	0.3	0.3	0.3	0.4	0.4	0.4	0.4
Silicon Carbide Production	+	+	+	+	+	+	+
Enteric Fermentation	32.7	32.8	33.2	33.6	34.5	34.9	34.5
Manure Management	14.9	15.4	16.0	16.1	16.7	16.9	16.6
Rice Cultivation	2.5	2.5	2.8	2.5	3.0	2.8	2.5
Agricultural Residue Burning	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Landfills	56.2	57.6	57.8	59.7	61.6	63.6	65.1
Wastewater Treatment	0.9	0.9	0.9	0.9	0.9	0.9	0.9
N₂O	92.3	94.4	96.8	97.1	104.9	101.9	103.7
Stationary Sources	3.7	3.7	3.7	3.8	3.8	3.8	4.0
Mobile Sources	13.2	13.9	14.8	15.6	16.3	16.6	16.5
Adipic Acid	4.7	4.9	4.6	4.9	5.2	5.2	5.4
Nitric Acid	3.4	3.3	3.4	3.5	3.7	3.7	3.8
Manure Management	2.6	2.8	2.8	2.9	2.9	2.9	3.0
Agricultural Soil Management	62.4	63.4	65.2	64.1	70.4	67.2	68.6
Agricultural Residue Burning	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Human Sewage	2.1	2.1	2.2	2.2	2.3	2.2	2.3
Waste Combustion	0.1	0.1	0.1	0.1	0.1	0.1	0.1
HFCs, PFCs, and SF₆	22.2	21.6	23.0	23.4	25.9	30.8	34.7
Substitution of Ozone Depleting Substances	0.3	0.2	0.4	1.4	4.0	9.5	11.9
Aluminum Production	4.9	4.7	4.1	3.5	2.8	2.7	2.9
HCFC-22 Production	9.5	8.4	9.5	8.7	8.6	7.4	8.5
Semiconductor Manufacture	0.2	0.4	0.6	0.8	1.0	1.2	1.4
Electrical Transmission and Distribution	5.6	5.9	6.2	6.4	6.7	7.0	7.0
Magnesium Production and Processing	1.7	2.0	2.2	2.5	2.7	3.0	3.0
Total Emissions	1,632.7	1,620.2	1,645.7	1,678.0	1,715.3	1,731.1	1,788.0
Net Emission (Sources and Sinks)	1,321.2	1,308.7	1,334.2	1,469.4	1,506.7	1,522.5	1,579.5

+ Does not exceed 0.05 MMTCE

* Sinks are only included in net emissions total. Estimates of net carbon sequestration due to land-use change and forestry activities exclude non-forest soils, and are based partially upon projections of forest carbon stocks.

Note: Totals may not sum due to independent rounding.

Table 1-3: U.S. Greenhouse Gas Emissions and Sinks (Tg)

Gas/Source	1990	1991	1992	1993	1994	1995	1996
CO₂	4,943.7	4,888.5	4,962.5	5,080.4	5,164.7	5,203.7	5,393.9
Fossil Fuel Combustion	4,881.9	4,826.9	4,900.7	5,014.1	5,095.2	5,128.5	5,317.8
Natural Gas Flaring	7.3	8.2	8.1	11.0	11.1	13.7	12.7
Cement Manufacture	32.6	31.9	32.1	33.9	35.4	36.1	37.1
Lime Manufacture	11.9	11.7	12.1	12.4	12.8	13.6	14.1
Limestone and Dolomite Use	5.1	4.9	4.5	4.1	5.3	6.5	6.7
Soda Ash Manufacture and Consumption	4.1	4.0	4.1	4.0	4.0	4.3	4.3
Carbon Dioxide Manufacture	0.8	0.8	0.9	0.9	0.9	1.0	1.1
Land-Use Change and Forestry (Sink) ^a	(1,142.2)	(1,142.2)	(1,142.2)	(764.7)	(764.7)	(764.7)	(764.7)
CH₄	29.7	29.9	30.1	30.0	30.7	31.3	31.2
Stationary Sources	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Mobile Sources	0.3	0.2	0.2	0.2	0.2	0.2	0.2
Coal Mining	4.2	4.0	3.8	3.4	3.4	3.6	3.3
Natural Gas Systems	5.7	5.8	5.9	5.9	5.9	5.9	5.9
Petroleum Systems	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Petrochemical Production	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Silicon Carbide Production	+	+	+	+	+	+	+
Enteric Fermentation	5.7	5.7	5.8	5.9	6.0	6.1	6.0
Manure Management	2.6	2.7	2.8	2.8	2.9	2.9	2.9
Rice Cultivation	0.4	0.4	0.5	0.4	0.5	0.5	0.4
Agricultural Residue Burning	+	+	+	+	+	+	+
Landfills	9.8	10.0	10.1	10.4	10.8	11.1	11.4
Wastewater Treatment	0.2	0.2	0.2	0.2	0.2	0.2	0.2
N₂O	1.1	1.1	1.1	1.1	1.2	1.2	1.2
Stationary Source	+	+	+	+	+	+	+
Mobile Sources	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Adipic Acid	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Nitric Acid	+	+	+	+	+	+	+
Manure Management	+	+	+	+	+	+	+
Agricultural Soil Management	0.7	0.8	0.8	0.8	0.8	0.8	0.8
Agricultural Residue Burning	+	+	+	+	+	+	+
Human Sewage	+	+	+	+	+	+	+
Waste Combustion	+	+	+	+	+	+	+
HFCs, PFCs, and SF₆	M	M	M	M	M	M	M
Substitution of Ozone Depleting Substances	M	M	M	M	M	M	M
Aluminum Production	M	M	M	M	M	M	M
HCFC-22 Production ^b	+	+	+	+	+	+	+
Semiconductor Manufacture	M	M	M	M	M	M	M
Electrical Transmission and Distribution ^c	+	+	+	+	+	+	+
Magnesium Production and Processing ^c	+	+	+	+	+	+	+
NO_x	21.6	21.6	21.9	22.2	22.6	21.7	21.3
CO	83.7	85.4	82.4	82.4	86.5	77.2	76.4
NMVOCs	18.8	18.9	18.5	18.7	19.3	18.4	17.0
+ Does not exceed 0.05 Tg							
M Mixture of multiple gases							
^a Sinks are not included in CO ₂ emissions total. Estimates of net carbon sequestration due to land-use change and forestry activities exclude non-forest soils, and are based partially upon projections of forest carbon stocks.							
^b HFC-23 emitted							
^c SF ₆ emitted							
Note: Totals may not sum due to independent rounding.							

Table 1-4: U.S. Greenhouse Gas Emissions and Sinks by Sector (MMTCE)

Sector	1990	1991	1992	1993	1994	1995	1996
Energy	1,412.5	1,397.6	1,418.6	1,448.4	1,471.3	1,482.3	1,532.7
Industrial Processes	45.5	44.7	45.9	47.2	51.2	56.9	61.5
Agriculture	115.5	117.3	120.3	119.5	127.9	125.0	125.4
Land-Use Change and Forestry (Sink)*	(311.5)	(311.5)	(311.5)	(208.6)	(208.6)	(208.6)	(208.6)
Waste	59.3	60.6	61.0	62.8	64.8	66.9	68.4
Total Emissions	1,632.7	1,620.2	1,645.7	1,678.0	1,715.3	1,731.1	1,788.0
Net Emission (Sources and Sinks)	1,321.2	1,308.7	1,334.2	1,469.4	1,506.7	1,522.5	1,579.5

* Sinks are only included in net emissions total. Estimates of net carbon sequestration due to land-use change and forestry activities exclude non-forest soils, and are based partially upon projections of forest carbon stocks.

Note: Totals may not sum due to independent rounding.

Greenhouse Gas Emissions from Transportation Activities

Motor vehicle usage is increasing all over the world, including in the United States. Since the 1970s, the number of highway vehicles registered in the United States has increased faster than the overall population, according to the Federal Highway Administration. Likewise, the number of miles driven—up 15 percent since 1990—and gallons of gasoline consumed each year in the United States has increased relatively steadily since the 1980s, according to the Energy Information Administration. These increases in motor vehicle usage are the result of a confluence of factors including population growth, economic growth, increasing urban sprawl, and low fuel prices.

One of the unintended consequences of these changes was a slowing of progress toward cleaner air in both urban and rural parts of the country. Passenger cars, trucks, motorcycles, and buses emit significant quantities of air pollutants with local, regional, and global effects. Motor vehicles were major sources of carbon monoxide, carbon dioxide (CO₂), methane (CH₄), nonmethane volatile organic compounds, nitrogen oxides, nitrous oxide (N₂O), and hydrofluorocarbons (HFCs). Motor vehicles were also important contributors to many serious air pollution problems, including ground level ozone or smog, acid rain, fine particulate matter, and global warming. Within the United States and abroad, government agencies have taken strong actions to reduce these emissions. Since the 1970s, the EPA has reduced lead in gasoline, developed strict emission standards for new passenger cars and trucks, directed states to enact comprehensive motor vehicle emission control programs, required inspection and maintenance programs, and

more recently, introduced the use of reformulated gasoline to mitigate the air pollution impacts from motor vehicles. New vehicles are now equipped with advanced emissions controls, which are designed to reduce emissions of nitrogen oxides, hydrocarbons, and carbon monoxide.

This report reflects new data on the role that automotive catalytic converters play in emissions of N₂O, a powerful greenhouse gas. The EPA's Office of Mobile Sources has recently conducted a series of tests in order to measure the magnitude of N₂O emissions from gasoline-fueled passenger cars and light-duty trucks equipped with catalytic converters. Results show that N₂O emissions are lower than the IPCC default factors and the United States has shared this data with the IPCC. Now, new emission factors developed from these measurements and from previously published literature were used to calculate emissions from mobile sources in the United States (see Annex C).

Table 1-5 summarizes greenhouse gas emissions from all transportation related activities. Overall, transportation activities accounted for an almost constant 26 percent of total U.S. greenhouse gas emissions from 1990 to 1996. These emissions were primarily CO₂ from fuel combustion, which increased by 8.8 percent from 1990 to 1996. However, because of larger increases in N₂O and HFC emissions during this period, overall emissions from transportation activities actually increased by 10.1 percent.

Table 1-5: Transportation Related Greenhouse Gas Emissions (MMTCE)

Gas/Vehicle Type	1990	1991	1992	1993	1994	1995	1996
CO₂	409.6	400.8	406.7	414.1	427.4	432.8	445.5
Passenger Cars ^a	169.3	167.8	172.0	173.5	172.5	160.0	163.2
Light-Duty Trucks ^a	77.5	77.2	77.2	80.5	87.2	104.9	107.1
Other Trucks	56.8	54.7	56.6	59.7	62.4	64.0	67.0
Buses	2.7	2.9	2.9	3.0	3.3	3.5	3.7
Aircraft	55.9	53.8	53.0	53.5	55.6	55.0	57.4
Boats and Vessels	16.3	15.0	15.3	13.4	13.7	12.5	13.2
Locomotives	7.4	6.9	7.4	6.7	8.0	8.1	8.5
Other ^b	23.7	22.4	22.4	23.7	24.8	24.9	25.5
CH₄	1.5	1.4	1.4	1.4	1.4	1.4	1.4
Passenger Cars	0.8	0.7	0.7	0.7	0.7	0.7	0.6
Light-Duty Trucks	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Other Trucks and Buses	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Aircraft	+	+	+	+	+	+	+
Boats and Vessels	0.1	0.1	0.1	+	+	+	+
Locomotives	+	+	+	+	+	+	+
Other ^c	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N₂O	13.2	13.9	14.8	15.6	16.3	16.6	16.5
Passenger Cars	8.7	9.1	9.7	10.1	10.0	10.1	10.1
Light-Duty Trucks	3.4	3.7	3.9	4.2	5.1	5.2	5.1
Other Trucks and Buses	0.7	0.7	0.7	0.7	0.8	0.8	0.9
Aircraft ^d	+	+	+	+	+	+	+
Boats and Vessels	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Locomotives	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other ^c	0.2	0.2	0.2	0.2	0.2	0.2	0.2
HFCs	+	+	0.2	0.7	1.3	2.5	3.6
Mobile Air Conditioners ^e	+	+	0.2	0.7	1.3	2.5	3.6
Total	424.3	416.1	423.2	431.7	446.4	453.3	467.0

+ Does not exceed 0.05 MMTCE

Note: Totals may not sum due to independent rounding.

^a In 1995, the U.S. Federal Highway Administration modified the definition of light-duty trucks to include minivans and sport utility vehicles.Previously, these vehicles were included under the passenger cars category. Hence the sharp drop in CO₂ emissions for passenger cars from 1994 to 1995 was observed. This gap, however, was offset by an equivalent rise in CO₂ emissions from light-duty trucks.^b "Other" CO₂ emissions includes motorcycles, construction equipment, agricultural machinery, pipelines, and lubricants.^c "Other" CH₄ and N₂O emissions includes motorcycles, construction equipment, agricultural machinery, gasoline-powered recreational, industrial, lawn and garden, light commercial, logging, airport service, other equipment; and diesel-powered recreational, industrial, lawn and garden, light construction, airport service.^d Aircraft N₂O emissions include aviation gasoline combustion but exclude jet fuel combustion due to insufficient data availability.^e Includes primarily HFC-134a

Electric Utility Related Greenhouse Gas Emissions

Like transportation, activities related to the generation, transmission and distribution of electricity in the United States result in greenhouse gas emissions. Table 1-6 presents greenhouse gas emissions from electric utility related activities. Overall emissions from electric utilities increased by 8.6 percent from 1990 to 1996, and accounted for just under 30 percent of total U.S. greenhouse emissions during the same period.

Table 1-6: Electric Utility Related Greenhouse Gas Emissions (MMTCE)

Gas/Fuel Type or Source	1990	1991	1992	1993	1994	1995	1996
CO₂	476.8	473.4	472.5	490.7	494.8	493.8	516.8
Coal	409.0	407.2	411.8	428.7	430.2	432.7	460.9
Natural Gas	41.2	41.1	40.7	39.5	44.0	47.2	40.3
Petroleum	26.6	25.1	19.9	22.5	20.6	14.0	15.6
Geothermal	0.1	0.1	0.1	0.1	+	+	+
CH₄	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Stationary Sources (Utilities)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N₂O	2.0	2.0	2.0	2.1	2.1	2.1	2.2
Stationary Sources (Utilities)	2.0	2.0	2.0	2.1	2.1	2.1	2.2
SF₆	5.6	5.9	6.2	6.4	6.7	7.0	7.0
Electrical Transmission and Distribution	5.6	5.9	6.2	6.4	6.7	7.0	7.0
Total	484.6	481.4	480.8	499.3	503.7	503.1	526.2

+ Does not exceed 0.05 MMTCE

Note: Totals may not sum due to independent rounding.

Methodology and Data Sources

Emissions of greenhouse gases from various sources have been estimated using methodologies that are consistent with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) except where noted otherwise. To the extent possible, the present U.S. inventory relies on published activity and emission factor data. Depending on the emission source category, *activity data* can include fuel consumption or deliveries, vehicle-miles traveled, raw material processed, etc.; *emission factors* are factors that relate quantities of emissions to an activity. For some sources, IPCC default methodologies and emission factors have been employed. However, for emission sources considered to be major sources in the United States, the IPCC default methodologies were expanded and more comprehensive methods were applied.

Inventory emission estimates from energy consumption and production activities are based primarily on the latest official fuel consumption data from the Energy Information Administration of the Department of Energy (EIA). Emission estimates for NO_x, CO, and NMVOCs were taken directly, except where noted, from

the United States Environmental Protection Agency's (EPA) report, *National Air Pollutant Emission Trends 1900 - 1996* (EPA 1997), which is an annual EPA publication that provides the latest estimates of regional and national emissions for ozone precursors (i.e., criteria pollutants). Emissions of these pollutants are estimated by the EPA based on statistical information about each source category, emission factors, and control efficiencies. While the EPA's estimation methodologies for criteria pollutants are conceptually similar to the IPCC recommended methodologies, the large number of sources EPA used in developing its estimates makes it difficult to reproduce the methodologies from EPA (1997) in this inventory document. In these instances, the sources containing detailed documentation of the methods used are referenced for the interested reader. For agricultural sources, the EPA criteria pollutant emission estimates were supplemented using available activity data from other agencies. Complete documentation of the methodologies and data sources used is provided in conjunction with the discussion of each source and in the various annexes.

Carbon dioxide emissions from fuel combusted in ships or aircraft engaged in the international transport of

passengers or cargo are not included in U.S. totals, but are reported separately as international bunkers in accordance with IPCC reporting guidelines (IPCC/UNEP/OECD/IEA 1997). Carbon dioxide emissions from fuel combusted within U.S. territories, however, are included in U.S. totals.

Uncertainty in and Limitations of Emission Estimates

While the current U.S. emissions inventory provides a solid foundation for the development of a more detailed and comprehensive national inventory, it has several strengths and weaknesses.

First, this inventory by itself does not provide a complete picture of past or future emissions in the United States; it only provides an inventory of U.S. emissions for the years 1990 through 1996. However, the United States believes that common and consistent inventories taken over a period of time can and will contribute to understanding future emission trends. The United States produced its first comprehensive inventory of greenhouse gas emissions and sinks in 1993, and intends to annually update this inventory in conjunction with its commitments under the FCCC. The methodologies used to estimate emissions will be periodically updated as methods and information improve, and as further guidance is received from the IPCC.

Secondly, there are uncertainties associated with the emissions estimates. Some of the current estimates, such as those for CO₂ emissions from energy-related activities and cement processing, are considered to be fairly accurate. For other categories of emissions, however, a lack of data or an incomplete understanding of how emissions are generated limit the scope or accuracy of the estimates presented. Within the discussion of each emission source, specific factors affecting the accuracy of the estimates are discussed.

Finally, while the IPCC methodologies provided in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) represent baseline methodologies for a variety of source categories, many of these methodologies continue to be improved and refined as new research and data becomes

available. The current U.S. inventory uses the IPCC methodologies where possible, and supplements them with other available methodologies and data where possible. The United States realizes that additional efforts are still needed to improve methodologies and data collection procedures. Specific areas requiring further research include:

Incorporating excluded emission sources. Quantitative estimates of some of the sources and sinks of greenhouse gas emissions are not available at this time. In particular, emissions from some land-use activities and industrial processes are not included in the inventory either because data are incomplete or because methodologies do not exist for estimating emissions from these source categories. See Annex Q for a discussion of the sources of greenhouse gas emissions excluded from this report.

Improving the accuracy of emission factors. Further research is needed in some cases to improve the accuracy of emission factors used to calculate emissions from a variety of sources. For example, the accuracy of current emission factors applied to methane and nitrous oxide emissions from stationary and mobile source fossil fuel combustion are highly uncertain.

Collecting detailed activity data. Although methodologies exist for estimating emissions for some sources, problems arise in obtaining activity data at a level of detail in which aggregate emission factors can be applied. For example, the ability to estimate emissions of methane and nitrous oxide from jet aircraft is limited due to a lack of activity data by aircraft type and number of landing and take-off cycles.

Applying Global Warming Potentials. GWP values have several limitations including that they are not applicable to unevenly distributed gases and aerosols such as tropospheric ozone and its precursors. They are also intended to reflect global averages and, therefore, do not account for regional effects (IPCC 1996).

Emissions calculated for the U.S. inventory reflect current best estimates; in some cases, however, estimates are based on approximate methodologies, assumptions, and incomplete data. As new information becomes available in the future, the United States will continue to improve and revise its emission estimates.

Changes in the U.S. Greenhouse Gas Inventory Report

In 1997, the Intergovernmental Panel on Climate Change released the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) that included multiple methodological changes and wholly new source categories. These revised IPCC guidelines along with other unrelated additions and methodological changes have been incorporated into this year's inventory of greenhouse gas emissions and sinks which, depending on the source, improve the accuracy, precision, or comprehensiveness of the estimates presented relative to previous U.S. inventories. In particular, several new N₂O sources have been included for the first time and revisions have been made to some existing sources that significantly increase overall N₂O emissions relative to previous U.S. inventories. A summary of the additions and changes made to this report is provided below:

- An improved methodology for estimating methane and nitrous oxide emissions from mobile sources was employed that accounts for changes in emission control technologies over time and vehicle miles traveled by model year. New N₂O emission factors were also used, based in part on new measurement data, which had the primary result of revising N₂O emission estimates from highway vehicles upward.
- An additional analysis of CO₂ emissions from fossil fuel combustion in the transportation end-use sector is provided showing emissions by fuel and vehicle type.
- Carbon sequestration from non-fuel uses of fossil fuels in U.S. territories was included for the first time in emission estimates of CO₂ from fossil fuel combustion.
- Due to inconsistencies in natural gas production and consumption data available from the Energy Information Administration, CO₂ emissions from unmetered natural gas consumption were not included. This exclusion had a insignificant effect on reported emissions.
- Carbon dioxide emissions from geothermal steam extraction for electric power generation were included for the first time, although its contribution to total emissions was less than 0.1 MMTCE.
- Improved emission factors and a more detailed analysis of activities contributing to methane emissions from natural gas systems were employed.
- Several new industrial processes were included for the first time. Methane emissions from the production of select petrochemicals and silicon carbide production were added, although their contribution was minor. Carbon dioxide emissions from ammonia, iron and steel, and ferroalloy production were explicitly estimated, even though their emissions are accounted for under the fossil fuel combustion of industrial coking coal and natural gas.
- The discussion of HFC, PFC, and SF₆ emissions has been expanded to include multiple sources and improved estimating methodologies.
- Estimates of nitrous oxide emissions from agricultural soil management have been considerably expanded to include direct and indirect emissions from organic fertilizers, cropping practices, and livestock manure management. Previous inventories simply accounted for emissions resulting from the application of synthetic fertilizers. As a result of this more comprehensive methodology, estimates have roughly tripled relative to previous years.
- Nitrous oxide emissions from manure management have been estimated for the first time.
- Additional crop types have been included in the analysis of emissions from agricultural residue burning.
- Carbon dioxide fluxes estimated from land-use change and forestry have been revised to include forest soils, forest understory, and non-forest soils. Additionally, estimates for carbon stocks in forest product pools now include wood harvested from public lands, which were previously excluded. These changes have more than doubled the flux estimates relative to previous year's inventories.
- An improved methodology for estimating methane emissions from landfills has been used, which tracks explicitly the shift to fewer, larger landfills.
- Nitrous oxide emissions from human sewage and waste combustion were estimated for the first time.